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AGE AND GROWTH OF SMALL ABALONE, *HALIOTIS DIVERSICOLOR SUPERTEXTA* (LISCHKE), IN HUALIEN, TAIWAN

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S. C. Peng, K. T. Shao and K. H. Chang (1984) Age and growth of small abalone, *Haliotis diversicolor supertexta* (Lischke), in Hualien, Taiwan. *Bull. Inst. Zool., Academia Sinica* **23**(1): 29-38. The age and growth of small abalone, *Haliotis diversicolor supertexta*, were studied by population sampling, tagging, and annulus reading methods from March 1979 to April 1981, in the coastal waters of Gi-Chi, Hualien, eastern Taiwan.

Analysis of population samples revealed that: (1) abalones larger than 60 mm were rare, (2) recruitment of the young abalone occurred in March, (3) the mean shell length of abalones of one and two years old was estimated to be 39.0 mm and 56.0 mm respectively, (4) new annuli formed during the period from April to May.

Growth rate estimated from tagged animals is in conformity with the result calculated from the population sampling method. In addition, both methods showed an obvious seasonal variation in growth rate of abalone; which grew rapidly from March to July, but slowed from August to March.

The annulus on the shell of abalone can be distinguished by the appearance of a narrow thick band on which ridges occurred. The mean shell length at annulus formation of abalones from one to five years old is 40.6, 58.1, 69.6, 77.9, and 84.9 mm, respectively. From the age-growth data, the von Bertalanffy growth equation for *H. diversicolor supertexta* was: $l_t = 100.0(1-e^{-0.3391(t+0.5248)})$.

The small abalone, *Haliotis diversicolor supertexta*, is an important commercial shellfish in Taiwan. The biology of reproduction of this species was reported by Tzeng (1976) and Tzeng and Lin (1976), and artificial propagation by Yang (1979). Also, the growth of this animal under different rearing environments was studied by Tzeng (1977). Though detailed information on age and growth would provide statistical background for fishery management, there is little information available for this animal in natural populations.

For growth and age determination of abalone three methods are generally applied. The age of *Haliotis* can be determined if apparent annuli form on the shell. For example, studies on the age and growth of *H. discus hannai* (Hujimoto, 1967; Kawamura *et al.*, 1970; Quayle, 1971; Sakai, 1962), *H. discus discus* (Kojima, 1975; Newman, 1968), *H. diversicolor aquatilis* (Oba, 1975), and *H. tuberculata* (Forster, 1967) were all based on annuli reading. Otherwise, the tagging method would be very practicable since it provides a direct approach to age determination, as indicated in studies of *H. midae* (Newman, 1968), *H. gigantea* (Kurogane *et al.*, 1974), *H. diversicolor diversicolor* (Nishimura, 1974), *H. tuberculata* (Forster, 1967; Hayashi, 1980), and *H. kamtschatkana* (Quayle, 1971). In addition, the population sampling method enables age

determination of young animals. Examples are shown in the studies of *H. midae* (Newman, 1968) and *H. tuberculata* (Hayashi, 1980).

To elucidate the age and growth of *H. diversicolor supertexta*, methods of population sampling, tagging, and annuli reading were employed in the present study.

MATERIALS AND METHODS

From March 1979 to April 1981, population sampling and tagging programs were conducted by SCUBA diving in an abalone reserve, at Gi-chi, Hualien, in depths ranging from five to eight meters.

For every specimen, shell length (L, the longest distance from the anterior end of outer respiratory pore to the tip of posterior end of the shell (Fig. 1)) was measured with a vernier caliper (Mitutopo) to 0.1 mm. After the water on the abalone was absorbed with gauze and deposits on the shell surface of the animal removed, body weight (W, wet weight) of the specimen was measured by a double beam balance (Kyoto Ishida) to 0.1 g.

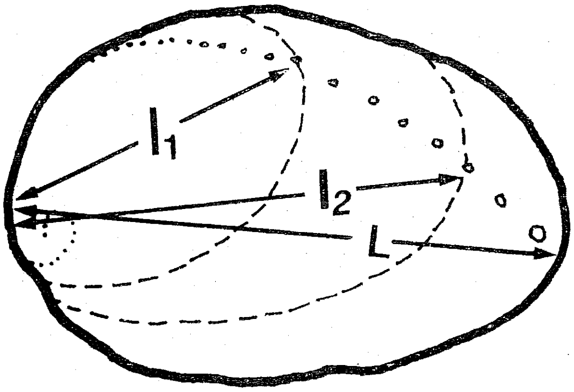

Fig. 1. Measurement of shell length (L) and annulus length (l_i, i indicates the i-th annulus) of *Haliotis diversicolor supertexta*.

Population sampling method

Sampling of abalone was undertaken in a selected area (10 m×10 m). During the sampling every movable boulder within this area was carefully examined to ensure that all abalone were removed. Specimens were taken ashore, measured and weighed as soon as possible. Based on the data, length frequency distribution polygons (Tesch, 1968), with 2 mm class interval, were drawn. The data were also plotted on probability paper with a 1 mm class interval according to the method described by Harding (1949) and Cassie (1954), to determine the mean shell length of each age-group in population sample. The variation of relationship of shell length to body weight between every two sampling dates was tested by covariance analysis (Snedecor & Cochran, 1967).

Tagging experiment

The abalones used for tagging were collected both from the abalone preserve and from nearby areas. A numbered acrylic tag ($5.4 \times 3.0 \times 0.75\ mm^3$) (American Floy Tag Company) or colored-bears tag was fastened to the shell of each abalone by threading a nylon line through the fourth and fifth anterior respiratory pores. The tagged abalones were placed one by one under rock shelters within a selected site by SCUBA divers. A total of 1140 individuals were tagged and released. During the recapture process, divers searched thoroughly for tagged individuals within a radius of twenty meters around the releasing site to ensure satisfactory recapture rate. Recaptured abalones were taken to the laboratory for the usual measurements, then returned to the sampling sites on the same or next day.

Abalones recaptured were sorted into 10 mm interval size classes according to their initial shell length at tagging. For each size class, determinations of possible seasonal variation in growth rates were made by regression analysis (Snedecor & Cochran, 1967).

Annulus reading method

For annulus reading methods, direct observation (Cox, 1962), X-ray photography (Wilbur and Owen, 1964), 10% HCl treatment, and heat treatment (Oba, 1975), were tested initially. The direct observation method was

adopted afterwards because it saved time and was more efficient. On the shell of abalone the feature of narrow thick bands on which ridges grew, was identified as an annulus. Annulus length (l_t) was then measured in the same way as the measurement of total shell length (Fig. 1).

From December 1980 to May 1981, marginal increments (l_m) of abalones randomly sampled from population sample were examined, The marginal increment was defined as:

$$l_m = L - l$$

where L is shell length and l is the outest annulus length. Three hundreds and eighty-nine shells, with shell lengths in a range from 22.15 mm to 95.75 mm, were collected for age determination.

RESULTS

A total of 3287 individuals was collected in the sampling period. Variation of growth for abalone is shown in length frequency distribution polygons of population samples. The mode for each age-group increases rapidly from March to July and slows down from August to March next year (Fig. 2). It implies that abalone grow rapidly from March to July but slowly from August to March. The seasonal representation of tagging data was then examined by testing the difference between particular seasonal growth coefficients represented in the three-variable regression equation for each size class:

$$G = b_0 + b_1 x_1 + b_2 x_2$$

where

G=growth increment

x_1=number of days within period March 1 to July 31

x_2=number of days within period August 1 to February 28, next year

b_0=error term

b_1=growth coefficient of March-July period

b_2=growth coefficient of August-February period

The growth coefficients for four size

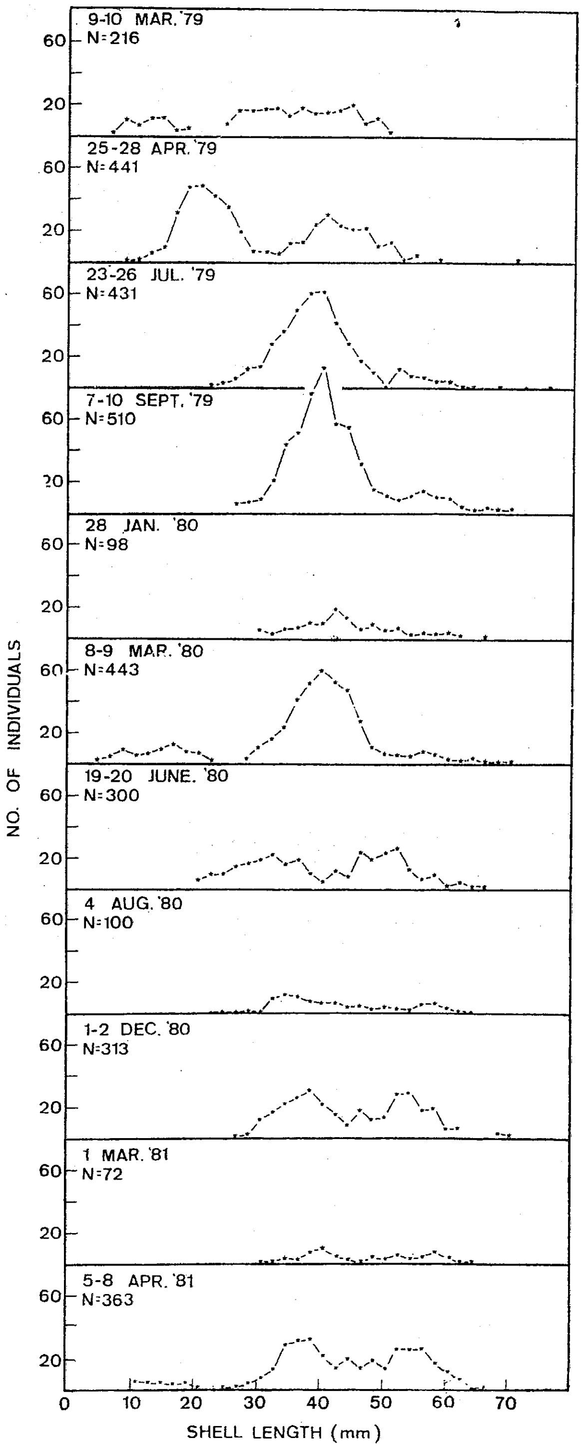

Fig. 2. Length frequency distribution polygons of six population samples of *Haliotis diversicolor supertexta*, N indicates number of individuals sampled on each sampling date.

TABLE 1

Coefficients of three-variable regressions fitted to tagging data

Size Class (mm)	b_1 (Mar.-July)	b_2 (Aug.-Feb.)	b_0	$\Delta\tilde{l}$ (mm)
20-30	0.1531	−0.0324	4.3674	20.91
30-40	0.1454	−0.0296	1.7624	17.73
40-50	0.0951	−0.0264	3.2530	12.21
50-60	0.0256	0.0054	1.8157	4.50

$\Delta\tilde{l}$: annual growth in length estimated from tagging data.

classes are listed in Table 1. The 10-20 mm size class is not presented because all individuals in that group were recaptured during the same growth period. One-tailed t-test for coefficients (Table 2) reveals that the probability of $b_1 > b_2$ is 0.999 for all size classes except the 50-60 mm one, which was not examined because its degree of freedom is only 1. That is, growth of abalone from March to July is more rapid than that from August to February.

Relationship between shell length (L) and body weight (W)

The shell length body weight relationships of the small abalone collected in population sampling method are significantly different in every two sampling dates (Table 3). Because the shell length body weight relationship is essential for population analysis, the overall data for abalones collected were combined to obtain a representative relationship between body weight (g) and shell length (mm). It shows that

$$W = 0.0001\ L^{2.9931}$$

TABLE 2

Results of one-tailed t-tests to determine the significance of differences between growth coefficients. b_1, Mar.-July; b_2, Aug.-Feb.

Size Class (mm)	df	Probability $b_1 > b_2$
20-30	21	0.999
30-40	35	0.999
40-50	14	0.999
50-60	1	—*

*: Not examined because $df = 1$.

TABLE 3

Results of covariance analysis of shell length body weight relationships for pairs of monthly samples

	Mar. 1979		Apr. 1979		Jul. 1979		Sept. 1979		Jan. 1980	
Apr. 1979	* * *	* * *								
Jul. 1979	* * *	* * *	* * *	* * *						
Sept. 1979	* * *	* * *	—	* * *	* * *	* * *				
Jan. 1980	—	* * *	—	* * *	—	* * *	—	* * *		
Mar. 1980	—	* * *	—	* * *	* * *	* * *	—	* * *	—	* * *
	Fb	Fa	Fb	Fa	Fb	Fa	Fb	Fa	Fb	Fa

—: no significant difference

* * *: significant at 0.1% level

Annulus formation

The composition of marginal increments of twenty random samples is shown in Fig. 3. The marginal increments increase slightly from December to May of the next pear. One individual was found to have a newly formed annulus in April, whereas in late May, 10 individuals bore newly formed annuli.

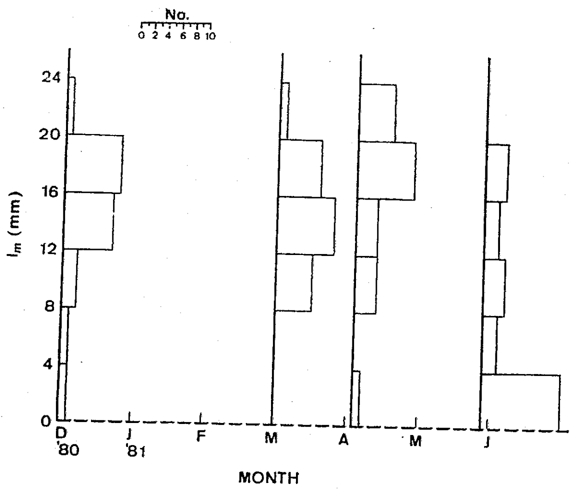

Fig. 3. Marginal growth (l_m) of *Haliotis diversicolor supertexta* in population samples.

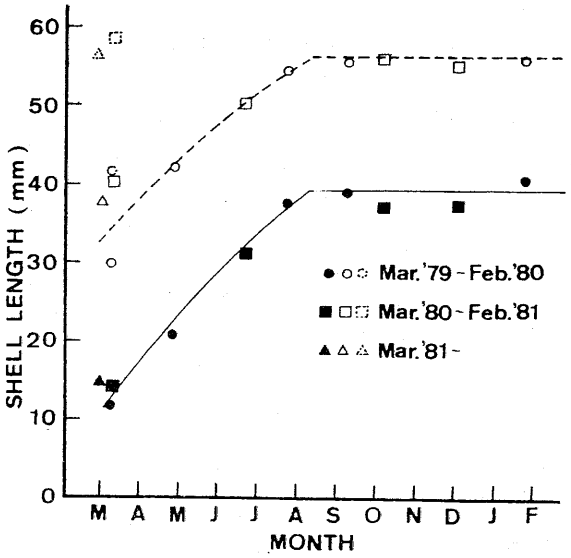

Fig. 4. Growth pattern for *Haliotis diversicolor supertexta*. The mean shell length of each age-group is shown as a function of time. Solid line, 1-year group; dash line, 2-year group. Both lines are prepared by free-hand method.

Growth

Population sample: The age-group was determined for each animal obtained in population sampling method. The spawning of *H. d. supertexta* in Gi-chi occurred from August to the following January (unpublished data), so that the first and second length-group in samples collected during these spawning season may be assigned to age I and age II group, respectively. The mean shell lengths of age I and age II group were estimated to be 38.0 and 55.0 mm, respectively (Fig. 4).

Tagging experiment: Among 1140 released abalones, 64 were recaptured. The annual increment of abalone represented by tag-return data was obtained by calculating the three-variable regression equation for each size class. Difference exists among annual increments for animals of different size classes. There is a tendency that the larger the abalone is, the smaller is its annual increment. The annual increments for size class 20–30 mm, 30–40 mm, 40–50 mm, and 50–60 mm are 20.9 mm, 17.7 mm, 12.2 mm, and 4.5 mm in sequence.

Annulus reading method: The linear regression relationship between shell length and annulus length in each age group is significant (Fig. 5). Mean annulus lengths of different age groups show no evidence of Lee's Phenomenon (Table 4). The shell lengths at annulus formation from ages one to five were calculated to be 40.6, 58.1, 69.6, 77.9, and 84.9 mm, respectively.

When shell length was used as a growth indicator, the relationship between l_t and l_{t+1} was obtained by applying Walford's graphic method, as in Fig. 6:

$$l_{t+1}=28.7716+0.7124l_t$$

From the equation, the parameters of the von Bertalanffy equation were determined as:

L(mm)	k	t_0
100.0	0.3391	−0.5248

Thus, the von Bertalanffy growth equation of *H. d. supertexta* in shell length becomes:

$$l_t=100.0(1-e^{-0.3391(t+0.5248)})$$

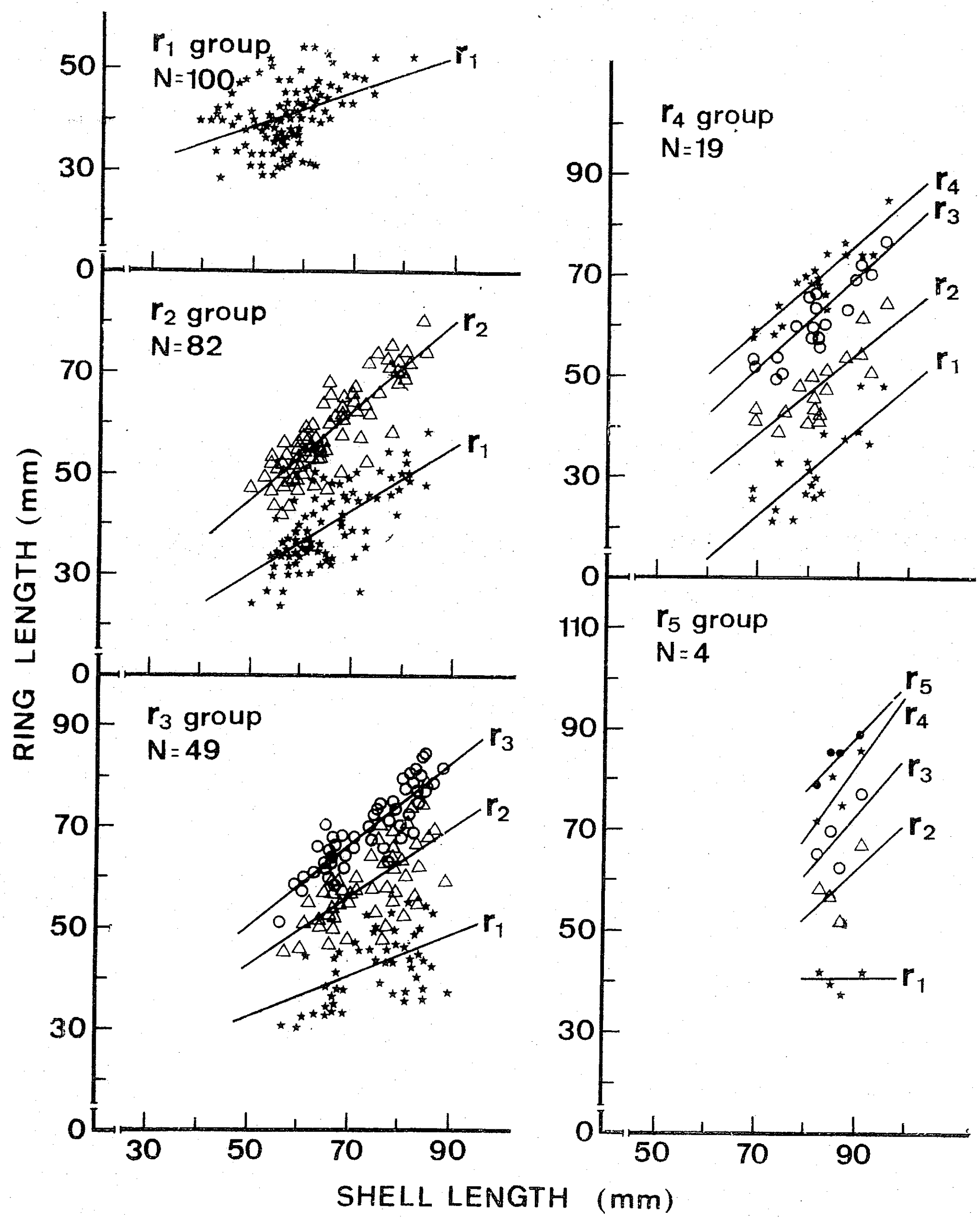

Fig. 5. The relationships between total shell length and each annulus length (ring length) of *Haliotis diversicolor supertexta* for specimens of different age groups. r_i indicates the i-th annulus.

TABLE 4
Shell length of *Haliotis diversicolor supertexta* at annulus formation

Age Group	No. of Shells	Mean Length of Annulus (mm)				
		l_1	l_2	l_3	l_4	l_5
I	100	39.8±6.6*				
II	82	39.8±7.7	58.1±8.5			
III	49	42.4±6.6	59.1±8.8	69.5±7.5		
IV	19	40.9±7.8	56.5±7.2	70.4±7.6	77.9±6.9	
V	4	40.3±2.2	58.7±6.1	69.0±6.4	77.9±6.3	84.9±4.1
Average		40.6	58.1	69.6	77.9	84.9

*: SD in length

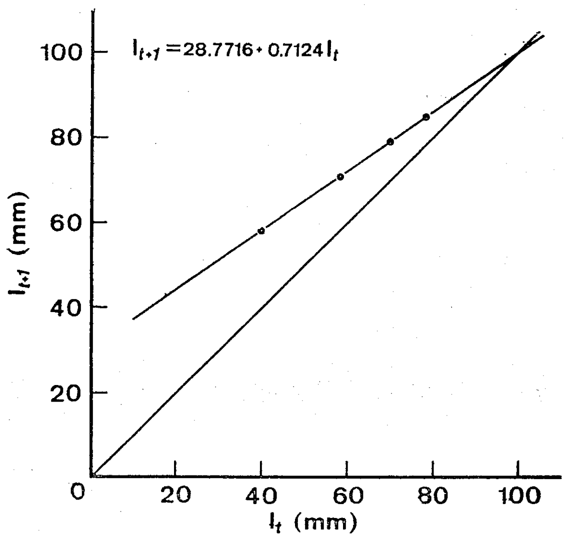

Fig. 6. Walford's growth transformation for shell length at annulus formation in *Haliotis diversicolor supertexta.*

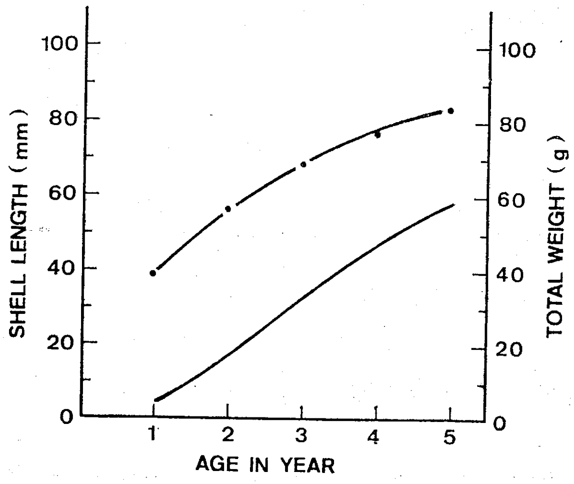

Fig. 7. von Bertalanffy growth curves for *Haliotis diversicolor supertexta.* Upper figure shows the growth curve in length, lower figure shows that in weight.

As shown in Fig. 6, the theoretical growth curve of abalones fits well with the calculated value. From the shell length body weight relationship obtained above, the von Bertalanffy growth equation in weight (g) is estimated as:

$$W=97.0(1-e^{-0.3391(t+0.5248)})^{2.9931}$$

DISCUSSION

Growth data obtained from both population sampling and tagging methods revealed a seasonal variation in the growth rate of abalones: they grew rapidly from March to July, and then slowed down from late July to March. Ino (1943; 1952) noted that the growth of *H. discus hannai* was correlated with the reproductive period: the feeding intensity of the animals declined at the onset of maturity, as did the growth rate; but after spawning, the feeding intensity increased and animals grew rapidly. Sakai (1962) found that the growth rate and production of *H. discus hannai* were positively related to production of algae, whereas Newman (1968; 1969) found that growth rate of *H. midae* was related to reproductive period and water temperature. In the present study, spawning of *H. d. supertexta* ceased in late January (unpublished data), whereas growth rate remained low until March. The mean

water temperature in Hualien increased progressively from March to July, to reach a maximum in the period from July to September, and then decreased subsequently until January (Taiwan Fish. Res. Inst., 1980). It seems that neither the reproductive period nor the water temperature is sufficient to explain the variation of growth rate, while algal abundance seems to show a positive correlation with the growth rate of these animals. Most of the macroalgae in local waters flourish after March, to form a verdant "algal bed" on the sea floor. When typhoons come in summer, a large quantity of algae is removed from their substrate by surge, and only few are left in the following northeast monsoon season. As for those abalones reared in the aquaria under ambient temperature, no significant seasonal variation is found in growth rate when sufficient food (*Ulva* spp.) is supplied throughout the experiment (unpublished data). Since algae are the major food items of the small abalone, the succession of algal floras may tend to influence the growth of this animal. It thus becomes explicable that the growth of the small abalone slacken in autumn and winter when macroalgae are found only in small quantity.

Seasonal temperature changes have been considered to be the cause of the formation of annuli: the more the temperature changes seasonally, the sharper the annuli may form (Tesch, 1968). The water temperature around Taiwan does not vary much, so that clear annuli might not be expected to form. In fact, annuli on abalone shells are observed to form during April to May (Fig. 3). These may be caused by the resumption of growth in this period. From the similarity of the mean shell lengths of age I and age II abalone estimated from annuli reading and from the population sampling methods, it was concluded that the first annulus on the shell of *H. d. supertexta* may form at one year old and other annuli may form yearly.

Few abalones larger than 60 mm were encountered either in population samples or by recapture of tagged animals. On the other hand, Quayle (1971) noted that the smallest tagged *H. kamtschatkana* recaptured was 60 mm; and Hayashi (1980) recorded that young *H. tuberculata* up to $1\frac{1}{2}$ years old were infrequently collected on the shore, probably because they inhabited different habitats from those of older ones or because their small size made them difficult to find. It has been reported by several authors that habitats of *Haliotis* vary with size of individual. In general, smaller animals live in more sheltered habitats such as the under surface or crevices of rocks, whereas larger animals are usually found exposed on rock surfaces and have a rather wider vertical distribution (Shepherd, 1973; Newman, 1966; 1969). During the present survey, divers noticed that large abalones tend to hide themselves under large boulders rather than small ones. Since sampling procedure was carefully designed to prevent bias arising from habitat preference, the scarcity of abalones larger than 60 mm may suggest a characteristic of the local population.

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臺灣花蓮產九孔 (*Haliotis diversicolor supertexta* Lischke) 年齡及成長的研究

彭秀琴 邵廣昭 張崑雄

自 1979 年三月到 1981 年四月，在花蓮縣磯崎村沿岸海域進行九孔 (*Haliotis diversicolor supertexta*) 族羣取樣及標識放流試驗，同時讀取空殼之年輪，以探討九孔的年齡及成長。

九孔族羣取樣樣品分析結果顯示 (1) 60 mm 以上個體在樣品中極爲稀少，(2)三月間開始有新加入羣出現，(3)由族羣樣品所估得九孔一、二歲之平均殼長爲 39.0 mm 及 56.0 mm，(4)九孔年輪約在 4 月～ 5 月間形成。

標識放流回收個體分析結果顯示九孔的成長具有明顯季節性差異：三月到七月間爲成長迅速期，八月到翌年三月爲成長緩慢期。

由年輪所估得一歲到五歲九孔年輪形成時之平均殼長分別爲 40.6 mm, 58.1 mm, 69.6 mm, 77.9 mm 及 84.9 mm。並由此求得九孔之 von Bertalanffy 成長方程式爲：

$$l_t = 100.0(1 - e^{-0.3391(t+0.5248)})$$